VII.13 Technology Validation: Fuel Cell Bus Evaluations

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Objectives

- Determine the status of fuel cell bus (FCB) technologies in transit applications by evaluating them in real-world service.
- Coordinate with the Federal Transit Administration (FTA) on the data collection for the National Fuel Cell Bus Program and international work groups to harmonize data collection methods and enable the comparison of a wider set of vehicles.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development, and Demonstration Plan:

(A) Lack of Fuel Cell Vehicle Performance and Durability Data

(C) Lack of Hydrogen Fueling Infrastructure Performance and Availability Data

(D) Maintenance and Training Facilities

Contribution to Achievement of DOE Technology Validation Technical Targets

- ***Milestone 2:*** *Demonstrate fuel cell vehicles that achieve 50% higher fuel economy than gasoline vehicles.* We are comparing nine heavy-duty first generation fuel cell vehicles of various configurations to baseline diesel or compressed natural gas (CNG) vehicles. Results for these first generation evaluations have shown:
  - Non-hybrid FCBs have a 12% lower fuel economy compared to diesel buses.
  - Hybrid FCBs have demonstrated a 71% higher fuel economy compared to diesel buses and a 141% higher fuel economy compared to CNG buses.
  - The hybrid hydrogen internal combustion engine (HHICE) bus has a 45% higher fuel economy than CNG buses.
- ***Milestone 8:*** *Fuel cell vehicles demonstrate the ability to achieve a 250-mile range without impacting the passenger cargo compartment.* Based on in-service fuel economies between 5 and 7 miles per kilogram, hybrid FCBs can achieve a range between 250 and 350 miles per fill. This efficiency is dependent on duty-cycle. There are no major issues with lost cargo/passenger space on transit buses because the tanks are typically mounted on the roof, however the added weight of the system limits the number of standing passengers allowed on the buses.

Accomplishments

- Collected, analyzed, and reported up to 27 months of performance and operational data on five full-size, hybrid FCBs and one HHICE bus in revenue service in the United States.
- Began data collection on next generation fuel cell system in revenue service.

Introduction

The transit industry has become an excellent "test-bed" for developing and optimizing advanced transportation technologies. Demonstrations of FCBs are being conducted in transit applications all over the world. Although progress has been made, more work is needed to improve reliability and durability of fuel cell systems to meet the needs of transit agencies.

Demonstration programs are necessary to validate the performance of the current generation of fuel cell systems. Lessons learned will help assess the status of FCB technology and determine issues that require further development. Early prototype FCBs have demonstrated improved performance characteristics–faster acceleration, lower noise, and no tailpipe emissions–over conventional buses

in transit applications. Barriers to the use of fuel cells in transportation applications need to be surmounted, however, before these technologies can be commercialized. Future evaluations should help address these issues, which include extending the life of fuel cells, improving reliability and durability of the systems, and lowering vehicle and infrastructure costs.

Approach

Researchers at NREL and Battelle have developed an evaluation protocol to provide:

- Comprehensive, unbiased evaluation results of advanced technology vehicle development and operations.
- Evaluations of hydrogen infrastructure development and operation.
- Descriptions of facility modifications required for the safe operation of FCBs.
- Detailed results on fuel cell systems for buses and the requisite hydrogen infrastructure to complement the light-duty demonstrations and further DOE goals.

The evaluation protocol includes two levels of data: operation and maintenance data on the bus and infrastructure, and more detailed data on the fuel cell, system, and components. The first set of data is considered non-sensitive and is obtained mainly from the transit fleet. The analysis, which consists of economic, technical, and safety factors, focuses on performance and use, including progress over time and experience with vehicle systems and supporting infrastructure.

The detailed data are collected with cooperation from the bus/fuel cell system manufacturers and are considered highly sensitive. Results will include aggregate data products that prevent identification of each manufacturer's specific data. NREL has begun to collect this data, and will publish aggregate results when enough data are available.

Results

Bus Evaluations

During Fiscal Year 2008, NREL collected data from three FCB demonstrations in the United States:

- Alameda-Contra Costa Transit District (AC Transit) in Oakland, CA.
- SunLine Transit Agency in Thousand Palms, CA.
- Connecticut Transit (CTTRANSIT) in Hartford, CT.

NREL has published detailed reports on two of the three demonstrations, including multiple data reports on both SunLine and AC Transit. Data for the first year of operation at CTTRANSIT are being analyzed and will be reported in summer of 2008. Data collection for a fourth project (Hickam Air Force Base) has been delayed because of technical issues with the bus. Results are expected to be available in the coming year. A summary of selected results from each project follows.

SunLine Transit Agency

SunLine has been operating one prototype fuel cell bus and one prototype HHICE bus in service. The fuel cell bus was manufactured by Van Hool and ISE Corp. It features an electric-hybrid drive system with a UTC Power fuel cell system and ZEBRA batteries for energy storage. The HHICE bus from New Flyer has essentially the same electric-hybrid drive system from ISE Corp., but with ultracapacitors for energy storage and a Ford V10 Triton engine customized to operate on hydrogen fuel. NREL collected operational and performance data on these two buses in comparison to five new CNG buses in the same operation. Three reports were published in 2007 and 2008. These reports outline the early experience and data results from the first generation fuel cell system. Table 1 summarizes a selection of the results.

During the evaluation period, SunLine operated the FCB nearly 51,000 miles and the HHICE bus over 43,000 miles. Using the CNG buses as the baseline, the fuel cell bus had an average monthly mileage 56% of CNG operation and the HHICE bus had average monthly mileage 63% of CNG operation.

Figure 1 shows the average monthly fuel economies for each of the three study groups of buses. The average fuel economy for the fuel cell bus fluctuated during the study. These have been due to several factors including fuel cell degradation, battery issues, and lack of fuel availability. Using the CNG buses as the baseline, the fuel cell bus had a fuel economy nearly 2.5 times higher than the CNG buses and the HHICE bus had a fuel

TABLE 1. Summary Data Results on SunLine

	FCB	HHICE	CNG
Number of buses	1	1	5
Data Period	Jan '06 – Mar '08		
Total fleet miles	50,931	43,523	454,680
Average miles per month	1,886	1,612	4,359
Total FC hours	3,918	--	--
Fuel economy (mi/diesel equivalent gal)	8.13	4.90	3.37
Average speed (mph)	12.8	12.8	13.2
Availability	66%	59%	83%
Fueling cost ($/mi)	1.11	2.43	0.53

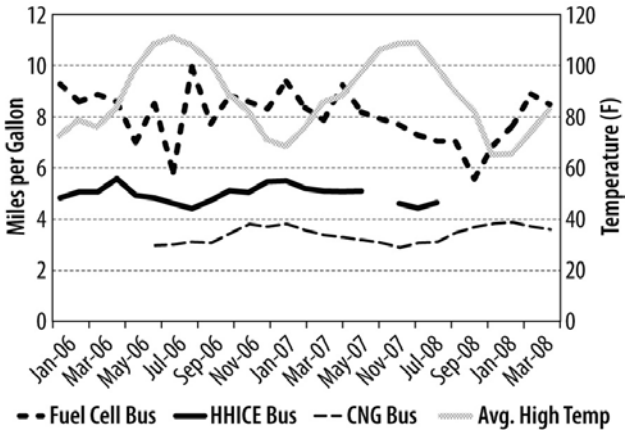

FIGURE 1. Monthly Fuel Economy (diesel equivalent), SunLine

economy 45% higher than the CNG buses. The fuel cell bus had a fuel economy 66% higher than the HHICE bus.

SunLine has an availability goal of 85% for all buses. The CNG buses were very close to this goal at 83%. Availability for the HHICE bus was much lower than reported previously, because of an engine failure. The fuel cell bus was much lower than the availability target because of problems with the air conditioning, batteries, and the fuel cell systems. When the air conditioning, batteries, and fuel cell systems were operating properly, the availability was generally close to the target.

AC Transit

AC Transit has been operating three fuel cell buses since March 2006. The fuel cell buses were manufactured by Van Hool and ISE Corp. They feature electric-hybrid drive systems with UTC Power fuel cell power systems and ZEBRA batteries for energy storage. The agency procured the buses to meet the demonstration requirements under the California Air Resources Board Transit Bus Fleet Rules. (Note: the FCB at SunLine was included in this procurement and is essentially identical to the buses at AC Transit.)

NREL collected operational and performance data on these buses in comparison to six similar Van Hool diesel buses in the same operation. Two reports outlining the early experience and data results were published in 2007. Table 2 summarizes a selection of the results.

At the beginning of the demonstration, AC Transit operated only two of the three fuel cell buses in service on any given weekday to allow for maintenance, training, and special events. As the demonstration has progressed, the agency has accelerated the testing of the buses; operating each bus for up to 14 hours per day including some weekend service. During the evaluation period, the fuel cell buses operated more than 76,000

TABLE 2. Summary Data Results on AC Transit

	FCB	Diesel
Number of buses	3	6
Data Period	Apr '06 – Mar '08	
Total fleet miles	76,159	459,096
Average miles per month	1,058	3,188
Total FC hours	7,234	--
Fuel economy (mi/diesel equivalent gal)	7.25	4.23
Average speed (mph)	10.8	N/A
Availability	55%	85%
Fueling cost ($/mi)	1.25	0.57

miles and more than 7,000 total fuel cell system hours. The usage of the fuel cell buses was approximately one third less than the diesel baseline buses in the same timeframe. Overall availability for the fuel cell buses was 55%. The primary reasons for this lower availability were battery and fuel cell system related.

Monthly average fuel economy for the fuel cell buses is shown in Figure 2. The fuel cell buses averaged 6.41 miles per kg of hydrogen for the evaluation period, which equates to 7.25 miles per diesel gallon equivalent. The average fuel consumption for the diesel buses was 4.23 mpg, which indicates that the fuel cell buses have an average fuel economy 71% higher than the diesel buses.

The operating cost for hydrogen production and dispensing for AC Transit is currently estimated at $8 per kg. This excludes capital expenses and was generated using early data (not optimized operation) and conservative maintenance and operating estimates. Full analysis using the H2A tool would be necessary to generate a hydrogen cost estimate comparable to research program production targets. This equates to a cost for the fuel cell buses of $1.25 per mile. The average diesel fuel cost per gallon during the evaluation

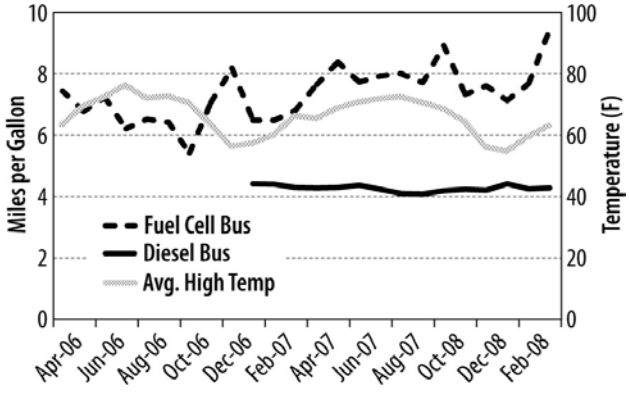

FIGURE 2. Monthly Fuel Economy (diesel equivalent), AC Transit

period was $2.39 per gallon, which equates to a cost of $0.57 per mile.

CTTRANSIT

CTTRANSIT began operating its fuel cell bus in revenue service beginning in March 2007. The fuel cell bus is essentially the same system as the buses at AC Transit and SunLine. This demonstration site is the first cold weather location for this bus.

NREL collected operational and performance data on the bus in comparison to three of CTTRANSIT's newest diesel buses, which are 40-foot New Flyer buses. The fuel cell bus is currently being operated on a downtown circulator route, which involves low-speed, stop-and-go driving. The diesel buses are operated on all of CTTRANSIT's routes, which results in a faster average speed. Table 3 summarizes a selection of the results.

During the evaluation period, the fuel cell bus operated 9,298 miles and 1,596 fuel cell system hours. The usage of the fuel cell bus was less than one third that of the diesel baseline buses in the same timeframe. Overall availability for the fuel cell bus was 53%. CTTRANSIT's goal for availability for their fleet is 85%.

Monthly average fuel economy for the fuel cell bus and diesel buses is shown in Figure 3. The fuel cell bus averaged 4.96 miles per kg of hydrogen for the evaluation period, which equates to 5.6 miles per diesel gallon equivalent. The diesel buses averaged 3.64 mpg. Using the diesel buses as a baseline, the fuel cell bus has an average fuel economy 54% higher.

CTTRANSIT fuels its fuel cell bus at the UTC Power hydrogen station. The cost for hydrogen for CTTRANSIT is currently $4.18 per kg. This equates to a cost for the fuel cell buses of $0.84 per mile. The average diesel fuel cost per gallon during the evaluation period was $2.51 per gallon, which equates to a fueling cost of $0.69 per mile.

TABLE 3. Summary Data Results on CTTRANSIT

	FCB	Diesel
Number of buses	1	3
Data Period	Apr '07 – Mar '08	
Total fleet miles	9,298	70,236
Average miles per month	775	2,932
Total FC hours	1,596	--
Fuel economy (mi/diesel equivalent gal)	5.60	3.64
Average speed (mph)	10	12
Availability	53%	85%
Fueling cost ($/mi)	0.84	0.69

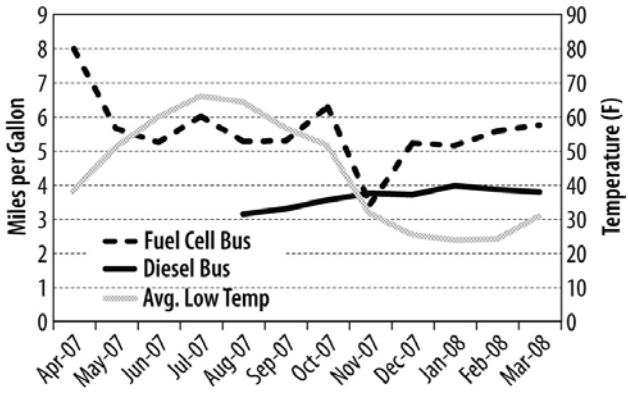

FIGURE 3. Monthly Fuel Economy (diesel equivalent), CTTRANSIT

FTA Data Collection/International Coordination

NREL has been funded by FTA to conduct evaluations of each of the demonstrations under its National Fuel Cell Bus Program. The evaluations will follow the same protocol as that of the DOE funded evaluations. This will provide similar data and analysis on a wider array of fuel cell systems in buses, which will aid in determining the progress of the technology toward market readiness. Through the FTA funding NREL also continues to work with international groups to collaborate among FCB demonstrations worldwide. A core group of agencies–NREL, FTA, the Electric Drive Transportation Association, the Northeast Advanced Vehicle Consortium, and HyFLEET CUTE–coordinated the 5th International Fuel Cell Bus Workshop in Reykjavik, Iceland, in May 2008.

Conclusions and Future Directions

Fuel cell propulsion systems, such as those used in the demonstration buses, are first generation prototypes in the early stages of technological development. These evaluations are helping to build a base of vehicle and infrastructure data that will facilitate understanding and determine future resource needs. Results from these first generation demonstrations show that there are challenges to overcome and more data are needed to measure progress. Remaining challenges include:

- Costs of purchasing, operating, and maintaining buses and infrastructure.
- Durability/reliability of the fuel cell systems and other components.
- Fully trained transit personnel to maintain all aspects of the buses.

Future work includes:

- Collect, analyze, and report on performance data of next generation hydrogen-fueled vehicles in service at the following sites:

  - Hickam Air Force Base
  - AC Transit District
  - SunLine
  - Connecticut Transit
  - Santa Clara Valley Transportation Authority
  - Additional sites as funding allows
- Investigate reliability, durability, and life cycle of FCBs as a part of ongoing evaluations; these efforts complement the DOE light-duty fuel cell vehicle demonstrations.
- Coordinate with FTA to ensure harmonized data collection efforts for the National Fuel Cell Bus Program.
- Coordinate with FTA to plan the 6th International Fuel Cell Bus Workshop in 2009.

FY 2008 Publications/Presentations

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